Near Surface Kinetic Energy Dissipation and its Relationship to Wavenumber-Directional Properties of Waves

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LONG-TERM GOALS

To establish the dependence of kinetic energy dissipation rate in the upper layers on wind forcing, column stability and wave breaking intensity as reflected in the degree of saturation of the wavenumber spectrum.

To parameterize the effect of sea state, including swells on the air-sea fluxes of momentum, heat and mass.

OBJECTIVES

It is now established that turbulent kinetic energy dissipation rates near the surface are strongly enhanced over `law-of-the-wall' shear layer estimates in conditions of breaking waves. The long term goal of this work is to obtain a parameteric description of the vertical structure of kinetic energy dissipation in the near surface zone beneath both breaking and non-breaking waves. The governing parameters include wind forcing, buoyancy flux, depth and wave properties, viz: wave age, wave height and steepness, and degree of wave breaking. Models of the ocean mixed layer have not typically taken the enhanced dissipation into account. Such a parameterization provides ocean modelers with an important boundary condition in coupled atmospheric-oceanic models.

A second objective of this work is to determine the effects of sea state on air-sea fluxes. Recent results have shown that the drag coefficient decreases strongly with wave age, and also that the presence of swells affects the wind stress direction, and results in increased scatter in the magnitude of wind stress. Here, we look at quantifying the effect of swell (its wave age, direction and energy relative to the wind sea) on the stress magnitude, with the goal of explaining some of the high variability typical of field results, especially at lower wind speeds.

APPROACH

During two field seasons, an extensive data set was collected from the launch AGILE – see Figure 1. The principal measurements were: Kinetic energy dissipation in the near surface region was measured by two hot wire probes and two miniature acoustic time-of-flight current meters (Fig. 2) on a profiling mast in front of the ship; the wind stress and buoyancy flux were measured by an ultrasonic anemometer and a wet/dry thermocouple psychrometer system mounted on a mast at the

Figure 1: R/V Agile on hoist, with profiling mast deployed.

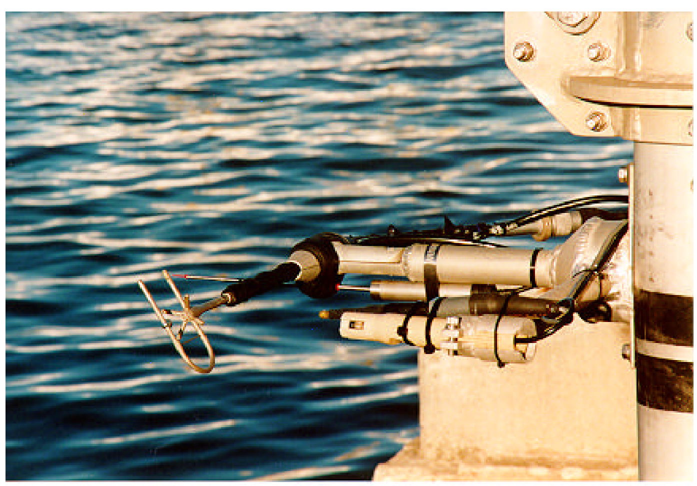


Figure 2: Close-up of acoustic current meter and hotfilm (red)

bow at 8m above the water surface; direct dissipation in the air was measured via hot-film anemometry; directional wave spectra were estimated using MLM on surface elevation signals from a fixed capacitance wave staff array, accounting for the measured ship motion. The ship motion was measured, and the anemometer signals are corrected as described in Anctil et al 1994, so that eddy-correlation fluxes could be determined.

WORK COMPLETED

SWADE and HIRES data have been analyzed to obtain eddy-correlation measurements of momentum, heat and moisture flux, along with directional wave spectra. The wind stress results from the SWADE/HIRES discus buoys have been accepted for publication. A manuscript describing the heat and moisture flux results from the SWADE swath ship is under preparation (with K.B. Katsaros, AOML).

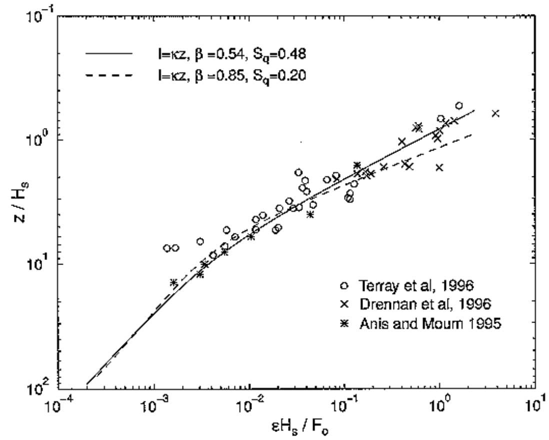
The wind stress data from the WAVES experiments (Lake Ontario) have been analyzed, and studied with the goal of determining wave effects (wave age and swell) on near surface turbulence, including momentum flux. A manuscript has been submitted to Boundary-Layer Meteorology.

Based on TKE dissipation rate data from the SWADE and WAVES experiments, a Mellor-Yamada level 2.5 turbulence closure scheme has been used to model dissipation and current profiles in the upper ocean (with E.A. Terray, WHOI). A manuscript is under preparation.

RESULTS

Terray et al (1996) proposed a scaling for dissipation rate which depends explicitly on the wave spectrum. They also determined that the significant wave height is an appropriate vertical scaling for the enhanced dissipation region. We (along with E. Terray, WHOI) have used these results to develop a turbulence model of the upper ocean based on a Mellor-Yamada order 2.5 turbulence closure scheme. The model builds on the earlier work of Craig and Banner (1994). In particular, the energy input at the surface, F, is determined from wave spectral parameters (for young waves, $F \approx u_{*w}^2 c_p/2$, where u_{*w} is the friction velocity in water, and c_p the phase speed of the wave peak, Terray et al 1997). Also, the appropriate roughness length was found to be κz for depths greater than $z_o = 0.54\ H_s$, where κ is von Kármán's constant. With this single set of parameters we are able to model both the recent dissipation data (Fig. 3), and surface current data (Fig. 4).

During the SWADE and HIRES experiments, over 900 hours of coincident eddy correlation wind stress and directional wave data were collected from 3m discus buoys equipped with K-Gill anemometers and motion packages. The data were examined for the effects of swell and unsteady winds on the magnitude of the drag coefficient. It was found that in situations where the swell is running against the wind, drag coefficients are significantly enhanced over both the remaining data, and commonly used drag coefficient parameterizations (e.g. Smith 1980). This supports the results of Donelan et al (1997) based on a more limited data set, and indicates the importance of including wave information in parameterizations of air-sea fluxes.



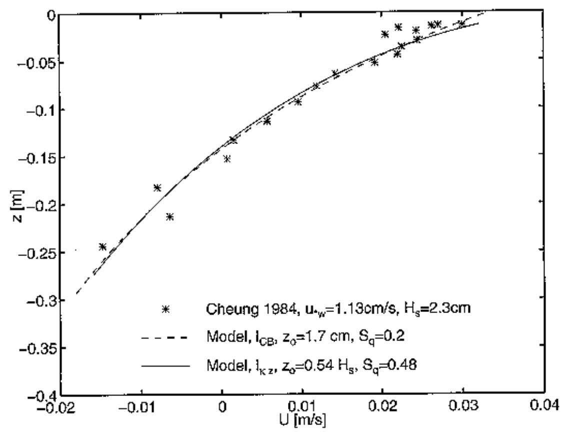


Figure 3: Predictions of dissipation rate from Terray and Drennan model showing dependence on $b=z_o/H_s$ and S_q.

Figure 4: Predictions of surface currents from Terray and Drennan model. Craig (1996) results also shown.

IMPACT/APPLICATION

Both the effect of swell or mixed swell-wind sea on the stress and the modeling of the upper layer dissipation have a significant impact on advanced upper layer models and coupled ocean-atmosphere models.

TRANSITIONS

Our methodology for wind stress and wave directional properties on moored buoys has been adopted for use by the Naval Postgraduate School. NPS deployed a cylindrical buoy with three wave staffs, using technology transferred by us, in the Norwegian Sea during NORSCEX and in Monterey Bay during EOPACE (Electro-Optical Propagation Assessment in Coastal Environments).

Work identifying the parameters of the Mellor-Yamada scheme for modeling the upper ocean was presented at several conferences. Resulting informal discussions appear to be leading to an inclusion of the results into upper-ocean models.

RELATED PROJECTS

ONR shoaling waves DRI. These methods and results will be applied on the ONR Shoaling waves experiments to be realized at Duck, NC in the fall of 1999. Measurements of wave directional properties, wind stress and K.E. dissipation will be made from a SWATH ship and several ASIS buoys.

The Air-Sea Interaction Spar (ASIS) buoy developed under ONR funding (Graber et al 1998, submitted to *J. Atmos. Oceanic Technol*) has been successfully deployed in the Gulf of Mexico, and the western Mediterranean. It measures high resolution directional wave spectra using a centered pentagon array of wave staffs as well as high quality stress components using sonic anemometry. This buoy has the potential to acquire many months of data at a fraction of the cost of ships, and will ultimately give the statistical data base necessary to resolve many of the outstanding air-sea interaction problems.

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